LOW CYCLE FATIGUE LIFE ESTIMATION OF A TURBINE BLISK

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ABSTRACT:
This paper deals with low cycle life estimation of a turbine blisk. The turbine blisk operates at extreme conditions; hence it is subjected to aerodynamic loads and high centrifugal loads. The loads on the turbine blisk vary due to the mission profile of the vehicle that includes takeoff, cruise and landing. An elastic-plastic finite element analysis is carried out. The life at the obtained stress and strain values is estimated using nCode DesignLife tool. Strain life approach is followed to estimate the life and Smith Watson Topper's approach is followed to carry out the mean stress correction.

Keywords: *Turbine Blisk, Low Cycle Fatigue, Strain-Life Approach, Palmgren-Miner's Rule, Mean Stress Correction.*

1. INTRODUCTION

The integrated blade and disc are together known as Blisk. The term fatigue life estimation stands for estimating the number of load cycles a structure can withstand before failure. Fatigue is a critical failure phenomenon in most of the heavy loaded components. The turbomachines are the heavy loaded parts of an engine, which makes them the critical parts of an engine [1, 2]. Hence, life estimation is a must for turbomachines.

The small turbine engines used in UAV,s are expected to have life lesser than the conventional engines used in commercial aircraft. Hence, low cycle fatigue estimation has to be carried out [3]. As the life expected is less, plastic deformation is permissible during the operation. As the structure is undergoing plastic deformation and is low cycle fatigue life estimation has to be carried out, strain life approach is the best suited life estimation method.

2. METHODOLOGY

A life estimation flow chart is presented in Fig.1 gives an outlook of the methodology followed in estimating fatigue life of the turbine blisk.

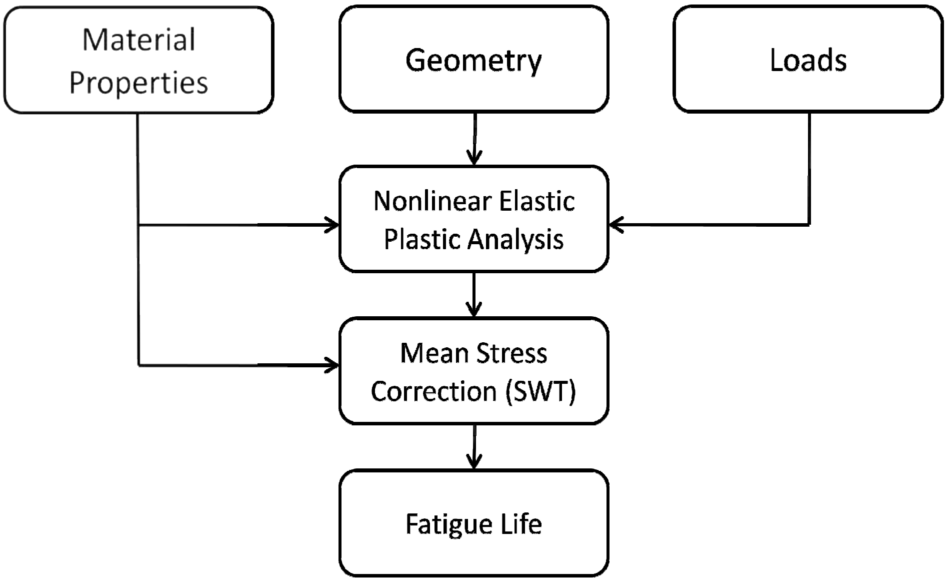

Fig 1. Design Flow Chart of Turbine Blisk

2.1. Geometry

The geometry considered in this paper is a turbine blisk with 43 blades. Geometry of $1/43^{rd}$ sector of the blisk containing one blade is shown in Fig.2.

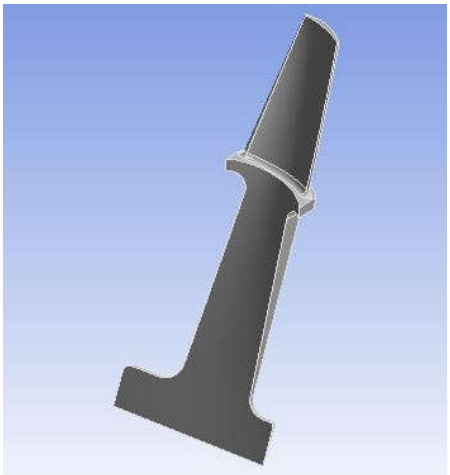

Fig 2. Sector Model of Turbine Blisk

2.2 Loads

The load profile of turbine blisk considered in this study consists of start, cruise (47575 rpm) and shutdown. The pressure loads due to the gases flowing on the blade at 47575 rpm are applied on the blade and a rotational velocity of 47575 rpm is applied to the turbine blisk. The Fig.3 shows load profile of this blisk during its operation.

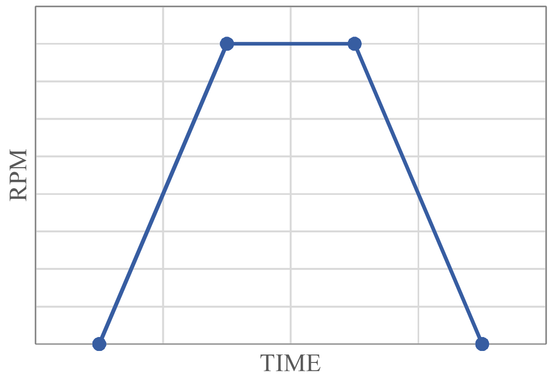

Fig 3. Load Profile of Turbine Blisk

2.3. Non-Linear, Cyclic and Fatigue Properties

NIMONIC 105, a nickel base superalloy [4] is the material of choice in this paper. Superalloys have the capacity to offer high strength up to higher fraction of their melting point, where as the other conventional materials lose their strength with rise in temperature. The non-linear (Bilinear) stress-strain curve of NIMONIC 105 [10] is fed into the FEM software . The non-linear stress strain curve for Nimonic 105 is shown in Fig.4. Where, the abscissa represents the stress and the ordinate represents the strain.

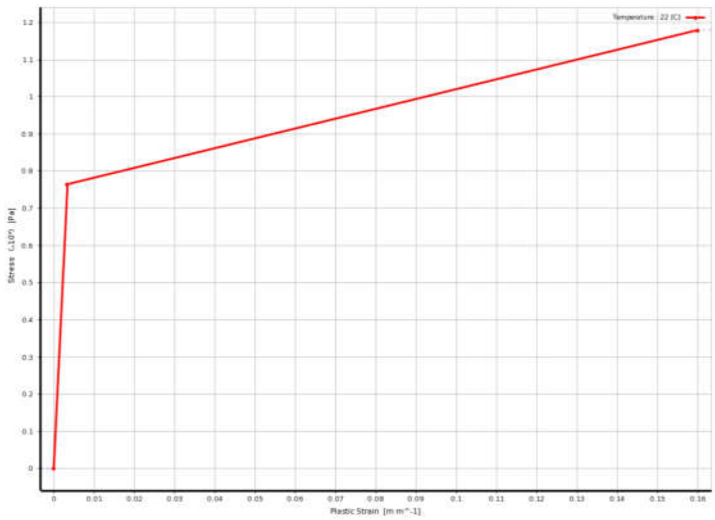

Fig 4. Stress-Strain Curve for Nimonic 105

Four fatigue and two cyclic properties are required to carry out the life estimation. These properties are derived from monotonic properties of the chosen material [8, 9]. The E-N curve (Coffin-Manson curve) is obtained using these properties. The E-N curve (Coffin-Manson curve) for NIMONIC 105 is shown in Fig.5. Where, the abscissa represents the strain amplitude in Log_{10} scale and the ordinate represents the reversals to failure (2N) in Log_{10} scale. The blue curve represents the elastic strain component, red curve represents the plastic strain component and the black curve is the E-N curve which is summation of these two components.

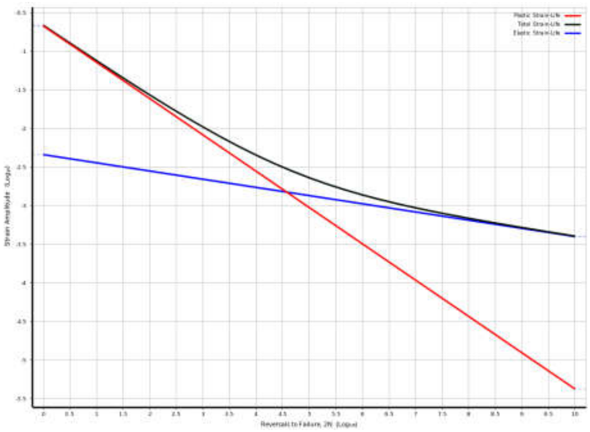

Fig 5. E-N Curve for Nimonic 105

The monotonic, cyclic and fatigue material properties of NIMONIC 105 are listed in table.1.

Table 1. Material Properties of Nimonic 105

Young's Modulus, E (MPa)	223×10^3
Yield Strength (MPa)	765
Ultimate Tensile Strength (MPa)	836
Fatigue Strength Coefficient, σ'_f (MPa)	1770
Fatigue Strength Exponent, b	-0.079
Fatigue Ductility Coefficient, ε'_f	0.274
Fatigue Ductility Exponent, c	-0.6
Cyclic Strain Hardening Coefficient, K' (MPa)	2100.86
Cyclic Strain Hardening Exponent, n'	0.132

Bilinear kinematic hardening is the material hardening phenomenon chosen to account Bauschinger effect in the material [5].

2.4. Nonlinear Stress-Strain Analysis

A nonlinear static structural analysis is carried out in ANSYS Mechanical tool. The stresses and strains are captured for the applied load profile. Further, the life estimation is done using these stresses. The blade root is found to be the critical region in the blisk as the stresses were found to be maximum at this location.

2.5. Mean Stress Correction

The E-N curve obtained from the fatigue properties is applicable only when the stress ratio is -1 and the mean stress is zero. For the considered load profile, the mean stress is not zero, hence a mean stress correction (Smith-Watson-Topper's approach) is required [6, 7]. The Smith-Watson-Topper's fatigue curve expression is given by,

$$\sigma_{max}\varepsilon_a = \frac{{\sigma'_f}^2}{E}(2N_f)^{2b} + \sigma'_f\varepsilon'_f(2N_f)^{b+c} \quad (3)$$

Where, σ_{max} is the maximum stress, ε_a is the strain amplitude, $2N_f$ number of cycles (Fatigue Life).

3. RESULTS

The stresses are found to be maximum at the blade root (766.41MPa) and the strain at the same location is 7.629×10^{-3}. The stress distribution in blisk is shown in Fig.6.

The estimated fatigue life of the blisk is 9151 cycles. The life estimation carried out in nCode DesignLife tool is shown in Fig.7.

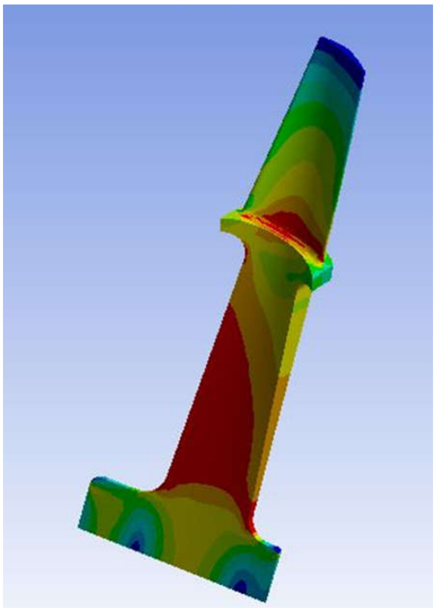

Fig 6. Distribution of Von Mises Stresses in The Turbine Blisk

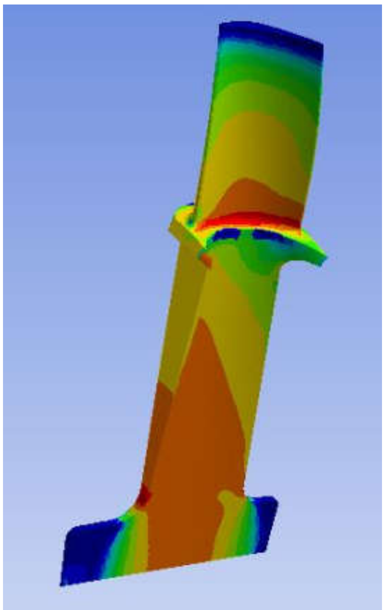

Fig 7. Fatigue Life of Turbine Blisk

4. CONCLUSION

In this study low cycle life estimation of a turbine blisk for a small gas turbine engine is carried out. A nonlinear elastic plastic FE analysis is carried out and the stresses and strains were found to me maximum at the blade root. The Strain-life approach is used to estimate the life as maximum stress (766.41MPa) obtained is above the yield strength of the material (765MPa). Smith-Watson-Topper's mean stress correction approach is used to estimate the fatigue life. The low cycle fatigue life of the tubine blisk is estimated to be 9151 cycles. The fatigue life obtained can be further increased or decreased for the required application by optimizing the design.

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